An Evaluation of Parchments’ Degradation: A Hybrid Approach

José Neves, José Machado, Guida Gomes
Algoritmi
Universidade do Minho
Braga, Portugal
{jenes, jmacc}@di.uminho.pt,
mguida.mgomes@gmail.com

Ana Teresa Caldeira, António Pereira, António Candeias
Departamento de Química
Escola de Ciências e Tecnologia
Universidade de Évora, Évora, Portugal
{atc, amlp, candeias}@uevora.pt

Sérgio Sousa, Daniela Tereso, Ana Coelho
Departamento de Química
Escola de Ciências e Tecnologia
Universidade de Évora, Évora, Portugal
{saeasousa, danny_tereso, alcoelho485}@gmail.com

Henrique Vicente
Departamento de Química
Escola de Ciências e Tecnologia
Universidade de Évora, Évora, Portugal
hvvicente@uevora.pt

KEYWORDS
Parchment Degradation, Logic Programming, Artificial Neural Networks, Knowledge Representation and Reasoning.

INTRODUCTION
Parchment denotes a material found in libraries, archives or museums, just to name a few. Maps, liturgical books, charters and other significant medieval manuscripts are examples of parchment artifacts that survived until today. It is an animal skin artifact that has been altered through chemical and physical means to resist putrefaction. It can be made from different animals skins, being produced in different ways and in dissimilar regions and times. These differences may result in disparate aging and reaction characteristics. Parchment, primarily originating from the hides of cattle, sheep, and goats, is predominantly composed of type I collagen. As the collagen degrades over time, the parchment loses strength, becomes brittle, and deteriorates to the point that it can no longer be used. The basis for the biodegradation of parchment is generally resulting from the biodegradation of collagen, but the presence of a lipid fraction may play an important contribution. The presence of lipids acting as a free radical generator upon interaction with atmospheric sulphur dioxide is suggested as a possible means of the degradation of the collagens. The formation of protein-lipid complexes may be an indication of collagen degradation, as similar conjugates are found in the aging process. Ghioni et al. (2005) suggest a relationship between collagen degradation and the increased lipid content of parchment. In general, the parchments can be degraded by internal and external factors. Internal factors are linked to the composition, types of glues, chemical residues and metal particles, while the external factors can be divided in biological, chemical, physical and mechanical.

One of the factors to be taken into account for the preservation of parchments is the Relative Humidity (RH) of the storage location. The most commonly encountered recommendations in the conservation literature for the storage and display of parchment are in the region of 50% RH to 65% RH. However, recommendations vary and include unspecified levels such as “complete dryness” for the display of parchment. Storage or display below around 25% RH is not indicated but decreasing the water content reduces (in both cases) the possibility of biodeterioration. A slightly higher value than 30% RH is suggested like a optimum condition for an object for the long-term preservation leaving intact collagen, the most important structural protein of animal cells (Hansen and Steve 1992). It can finally be referred that below 30% relative humidity results in the loss of physical properties of the parchments, while above 50% relative humidity induce type I collagen. As the collagen degrades over time, the parchment loses strength, becomes brittle, and deteriorates to the point that it can no longer be used. The basis for the biodegradation of parchment is generally resulting from the biodegradation of collagen, but the presence of a lipid fraction may play an important contribution. The presence of lipids acting as a free radical generator upon interaction with atmospheric sulphur dioxide is suggested as a possible means of the degradation of the collagens. The formation of protein-lipid complexes may be an indication of collagen degradation, as similar conjugates are found in the aging process. Ghioni et al. (2005) suggest a relationship between collagen degradation and the increased lipid content of parchment. In general, the parchments can be degraded by internal and external factors. Internal factors are linked to the composition, types of glues, chemical residues and metal particles, while the external factors can be divided in biological, chemical, physical and mechanical.

One of the factors to be taken into account for the preservation of parchments is the Relative Humidity (RH) of the storage location. The most commonly encountered recommendations in the conservation literature for the storage and display of parchment are in the region of 50% RH to 65% RH. However, recommendations vary and include unspecified levels such as “complete dryness” for the display of parchment. Storage or display below around 25% RH is not indicated but decreasing the water content reduces (in both cases) the possibility of biodeterioration. A slightly higher value than 30% RH is suggested like a optimum condition for an object for the long-term preservation leaving intact collagen, the most important structural protein of animal cells (Hansen and Steve 1992). It can finally be referred that below 30% relative humidity results in the loss of physical properties of the parchments, while above 50% relative humidity induce type I collagen. As the collagen degrades over time, the parchment loses strength, becomes brittle, and deteriorates to the point that it can no longer be used. The basis for the biodegradation of parchment is generally resulting from the biodegradation of collagen, but the presence of a lipid fraction may play an important contribution. The presence of lipids acting as a free radical generator upon interaction with atmospheric sulphur dioxide is suggested as a possible means of the degradation of the collagens. The formation of protein-lipid complexes may be an indication of collagen degradation, as similar conjugates are found in the aging process. Ghioni et al. (2005) suggest a relationship between collagen degradation and the increased lipid content of parchment. In general, the parchments can be degraded by internal and external factors. Internal factors are linked to the composition, types of glues, chemical residues and metal particles, while the external factors can be divided in biological, chemical, physical and mechanical.

One of the factors to be taken into account for the preservation of parchments is the Relative Humidity (RH) of the storage location. The most commonly encountered recommendations in the conservation literature for the storage and display of parchment are in the region of 50% RH to 65% RH. However, recommendations vary and include unspecified levels such as “complete dryness” for the display of parchment. Storage or display below around 25% RH is not indicated but decreasing the water content reduces (in both cases) the possibility of biodeterioration. A slightly higher value than 30% RH is suggested like a optimum condition for an object for the long-term preservation leaving intact collagen, the most important structural protein of animal cells (Hansen and Steve 1992). It can finally be referred that below 30% relative humidity results in the loss of physical properties of the parchments, while above 50% relative humidity induce type I collagen. As the collagen degrades over time, the parchment loses strength, becomes brittle, and deteriorates to the point that it can no longer be used. The basis for the biodegradation of parchment is generally resulting from the biodegradation of collagen, but the presence of a lipid fraction may play an important contribution. The presence of lipids acting as a free radical generator upon interaction with atmospheric sulphur dioxide is suggested as a possible means of the degradation of the collagens. The formation of protein-lipid complexes may be an indication of collagen degradation, as similar conjugates are found in the aging process. Ghioni et al. (2005) suggest a relationship between collagen degradation and the increased lipid content of parchment. In general, the parchments can be degraded by internal and external factors. Internal factors are linked to the composition, types of glues, chemical residues and metal particles, while the external factors can be divided in biological, chemical, physical and mechanical.

An Evaluation of Parchments’ Degradation: A Hybrid Approach

José Neves, José Machado, Guida Gomes
Algoritmi
Universidade do Minho
Braga, Portugal
{jenes, jmacc}@di.uminho.pt,
mguida.mgomes@gmail.com

Ana Teresa Caldeira, António Pereira, António Candeias
Departamento de Química
Escola de Ciências e Tecnologia
Universidade de Évora, Évora, Portugal
{atc, amlp, candeias}@uevora.pt

Sérgio Sousa, Daniela Tereso, Ana Coelho
Departamento de Química
Escola de Ciências e Tecnologia
Universidade de Évora, Évora, Portugal
{saeasousa, danny_tereso, alcoelho485}@gmail.com

Henrique Vicente
Departamento de Química
Escola de Ciências e Tecnologia
Universidade de Évora, Évora, Portugal
hvvicente@uevora.pt

KEYWORDS
Parchment Degradation, Logic Programming, Artificial Neural Networks, Knowledge Representation and Reasoning.

ABSTRACT
Parchment stands for a multifaceted material made from animal skin, which has been used for centuries as a writing support or as bookbinding. Due to the historic value of objects made of parchment, understanding their degradation and their conditions of utmost importance to archives, libraries and museums, i.e., the assessment of parchment degradation is mandatory, although it is hard to do with traditional methodologies and tools for problem solving. Hence, in this work we will focus on the development of a hybrid decision support system, in terms of its knowledge representation and reasoning procedures, under a formal framework based on Logic Programming, complemented with an approach to computing centered on Artificial Neural Networks, to reevaluate Parchment Degradation and the respective Degree-of-Confidence that one has on such a happening.

INTRODUCTION
Parchment denotes a material found in libraries, archives or museums, just to name a few. Maps, liturgical books, charters and other significant medieval manuscripts are examples of parchment artifacts that survived until today. It is an animal skin artifact that has been altered through chemical and physical means to resist putrefaction. It can be made from different animals skins, being produced in different ways and in dissimilar regions and times. These differences may result in disparate aging and reaction characteristics.

Parchment, primarily originating from the hides of cattle, sheep, and goats, is predominantly composed of type I collagen. As the collagen degrades over time, the parchment loses strength, becomes brittle, and deteriorates to the point that it can no longer be used. The basis for the biodegradation of parchment is generally resulting from the biodegradation of collagen, but the presence of a lipid fraction may play an important contribution. The presence of lipids acting as a free radical generator upon interaction with atmospheric sulphur dioxide is suggested as a possible means of the degradation of the collagens. The formation of protein-lipid complexes may be an indication of collagen degradation, as similar conjugates are found in the aging process. Ghioni et al. (2005) suggest a relationship between collagen degradation and the increased lipid content of parchment. In general, the parchments can be degraded by internal and external factors. Internal factors are linked to the composition, types of glues, chemical residues and metal particles, while the external factors can be divided in biological, chemical, physical and mechanical.

One of the factors to be taken into account for the preservation of parchments is the Relative Humidity (RH) of the storage location. The most commonly encountered recommendations in the conservation literature for the storage and display of parchment are in the region of 50% RH to 65% RH. However, recommendations vary and include unspecified levels such as “complete dryness” for the display of parchment. Storage or display below around 25% RH is not indicated but decreasing the water content reduces (in both cases) the possibility of biodeterioration. A slightly higher value than 30% RH is suggested like a optimum condition for an object for the long-term preservation leaving intact collagen, the most important structural protein of animal cells (Hansen and Steve 1992). It can finally be referred that below 30% relative humidity results in the loss of physical properties of the parchments, while above 50% relative humidity induce
loss of physical and chemical properties. It is accepted by some authors that the ideal range of relative humidity for storage is the one between 30% and 50%.

The degradation of the ink is another factor to pay attention. We can consider three different types of ink degradation. Hosing is when a light brown halo spreads out from the inked area. Burnthrough is when the ink appears to sink through the parchment and becomes increasingly visible on the reverse side, and Lacing is when the inked areas become so weak and brittle that they crack, crumble and fall out (Reibland and Groot 1999). In this paper we assume that Hosing is the level one of degradation, Burnthrough is the level two and Lacing is the third one and the worst in ink degradation.

Biological attacks can be induced by microorganisms, revealed by the appearance of spots of different colors, intensities and conformations or by insect action that may already be inside where the parchment is filed or may arise from objects already infested. It can also be via the action of rodents that invade the premises through windows, doors or the tubing.

The chemical attack may occur by environmental pollution (e.g. dust has a cutting and abrasive action leading to wear and damage on the scrolls). However, dirtiness is the deterioration agent that most affects mechanical degradation (due to the growing need to offer user support in decision making processes some studies have been presented (Halpern 2005; Kovařík and Roscini 2010) related to the qualitative models and qualitative reasoning in Database Theory and in Artificial Intelligence research. With respect to the problem of knowledge representation and reasoning in LP, a measure of the Quality-of-Information (QoI) of such programs has been object of some work with promising results (Lucas 2003; Machado et al. 2010). The QoI with respect to the extension of a predicate, will be given by a truth-value in the interval [0,1], i.e., if the information is known (positive) or false (negative) the QoI for the extension of predicate, is 1. For situations where the information is unknown, the QoI is given by:

\[ QoI = \frac{1}{\text{Card}(N)} \tag{1} \]

where \( N \) denotes the cardinality of the set of terms or clauses of the extension of predicate, that stand for the incompleteness under consideration. For situations where the extension of predicate is unknown but can be taken from a set of values, the QoI is given by:

\[ QoI = \frac{1}{\text{Card}(N)} \tag{2} \]

loss of physical and chemical properties. It is accepted by some authors that the ideal range of relative humidity for storage is the one between 30% and 50%.

The degradation of the ink is another factor to pay attention. We can consider three different types of ink degradation. Hosing is when a light brown halo spreads out from the inked area. Burnthrough is when the ink appears to sink through the parchment and becomes increasingly visible on the reverse side, and Lacing is when the inked areas become so weak and brittle that they crack, crumble and fall out (Reibland and Groot 1999). In this paper we assume that Hosing is the level one of degradation, Burnthrough is the level two and Lacing is the third one and the worst in ink degradation.

Biological attacks can be induced by microorganisms, revealed by the appearance of spots of different colors, intensities and conformations or by insect action that may already be inside where the parchment is filed or may arise from objects already infested. It can also be via the action of rodents that invade the premises through windows, doors or the tubing.

The chemical attack may occur by environmental pollution (e.g. dust has a cutting and abrasive action leading to wear and damage on the scrolls). However, dirtiness is the deterioration agent that most affects mechanical degradation (due to the growing need to offer user support in decision making processes some studies have been presented (Halpern 2005; Kovařík and Roscini 2010) related to the qualitative models and qualitative reasoning in Database Theory and in Artificial Intelligence research. With respect to the problem of knowledge representation and reasoning in LP, a measure of the Quality-of-Information (QoI) of such programs has been object of some work with promising results (Lucas 2003; Machado et al. 2010). The QoI with respect to the extension of a predicate, will be given by a truth-value in the interval [0,1], i.e., if the information is known (positive) or false (negative) the QoI for the extension of predicate, is 1. For situations where the information is unknown, the QoI is given by:

\[ QoI = \frac{1}{\text{Card}(N)} \tag{1} \]

where \( N \) denotes the cardinality of the set of terms or clauses of the extension of predicate, that stand for the incompleteness under consideration. For situations where the extension of predicate is unknown but can be taken from a set of values, the QoI is given by:

\[ QoI = \frac{1}{\text{Card}(N)} \tag{2} \]
where \( \text{Card} \) denotes the cardinality of the abducibles set for \( i \), if the abducibles set is disjoint. If the abducibles set is not disjoint, the \( \text{Qol} \) is given by:

\[
\text{Qol}_i = \frac{1}{C_{\text{Card}} + \cdots + \frac{1}{\text{Card}}} \tag{3}
\]

where \( C_{\text{Card}} \) is a card-combination subset, with \( \text{Card} \) elements.

The next element of the model to be considered is the relative importance that a predicate assigns to each of its attributes under observation, i.e., \( w^i_j \), which stands for the relevance of attribute \( k \) in the extension of \( \text{predicate}_i \). It is also assumed that the weights of all the attributes are normalized, i.e.:

\[
\sum_{k \in \text{attributes} \text{ of } \text{predicate}_i} w^i_k = 1, \forall_i \tag{4}
\]

where \( \forall \) denotes the universal quantifier. It is now possible to define a predicate’s scoring function \( V_i(x) \) so that, for a value \( x = (x_1, x_2, \ldots, x_n) \), defined in terms of the attributes of \( \text{predicate}_i \), one may have:

\[
V_i(x) = \sum_{k \in \text{attributes} \text{ of } \text{predicate}_i} w^i_k \cdot \text{Qol}_i(x)/n \tag{5}
\]

allowing one to set:

\[
\text{predicate}_i(x_1, \ldots, x_n) : = V_i(x) \tag{6}
\]

that denotes the inclusive quality of \( \text{predicate}_i \), with respect to all the predicates that make the program. It is now possible to set a logic program (here understood as the predicates’ extensions that make the program) scoring function, in the form:

\[
\text{LPScoring Function} = \sum_{i=1}^{n} V_i(x) \times p_i \tag{7}
\]

where \( p_i \) stands for the relevance of the \( \text{predicate}_i \), in relation to the other predicates whose extensions denote the logic program. It is also assumed that the weights of all the predicates’ extensions are normalized, i.e.:

\[
\sum_{i=1}^{n} p_i = 1, \forall_i \tag{8}
\]

It is now possible to engender the universe of discourse, according to the information given in the logic programs that endorse the information about the problem under consideration, according to productions of the type:

\[
\text{extensions of } \text{predicate}_i, = \sum_{k=1}^{l} \text{clause}(x_1, \ldots, x_n) : = \text{Qol}_i \cdot \text{DoC}_i \tag{9}
\]

where \( \land \) and \( \lor \) stand, respectively, for set union and the cardinality of the extension of \( \text{predicate}_i \). On the other hand, \( \text{DoC}_i \) denotes one’s confidence on the attribute’s values of a particular term of the extension of \( \text{predicate}_i \), whose evaluation will be illustrated below. In order to advance with a broad-spectrum, let us suppose that the Universe of Discourse is described by the extension of the predicates:

\[
f_1(\ldots), f_2(\ldots), \ldots, f_m(\ldots) \tag{10}
\]

Assuming that a clause denotes a happening, a clause has as argument all the attributes that make the event. The argument values may be of the type unknown or numbers of a set, or may be in the scope of a given interval, or may qualify a particular observation. Let us consider that the case data is given by the extension of predicate \( f_i \) in the form:

\[
f_i(x_1, x_2, x_3) = \{0, 1\} \tag{11}
\]

where \( \forall \) and \( \exists \) stand, respectively, for set union and the cardinality of the extension of \( \text{predicate}_i \). It is also assumed that the weights of all the attribute predicates are normalized, i.e.:

\[
\sum_{k \in \text{attributes} \text{ of } \text{predicate}_i} w^i_k = 1, \forall_i \tag{4}
\]

where \( \forall \) denotes the universal quantifier. It is now possible to define a predicate’s scoring function \( V_i(x) \) so that, for a value \( x = (x_1, x_2, \ldots, x_n) \), defined in terms of the attributes of \( \text{predicate}_i \), one may have:

\[
V_i(x) = \sum_{k \in \text{attributes} \text{ of } \text{predicate}_i} w^i_k \cdot \text{Qol}_i(x)/n \tag{5}
\]

allowing one to set:

\[
\text{predicate}_i(x_1, \ldots, x_n) : = V_i(x) \tag{6}
\]

that denotes the inclusive quality of \( \text{predicate}_i \), with respect to all the predicates that make the program. It is now possible to set a logic program (here understood as the predicates’ extensions that make the program) scoring function, in the form:

\[
\text{LPScoring Function} = \sum_{i=1}^{n} V_i(x) \times p_i \tag{7}
\]

where \( p_i \) stands for the relevance of the \( \text{predicate}_i \), in relation to the other predicates whose extensions denote the logic program. It is also assumed that the weights of all the predicates’ extensions are normalized, i.e.:

\[
\sum_{i=1}^{n} p_i = 1, \forall_i \tag{8}
\]

It is now possible to engender the universe of discourse, according to the information given in the logic programs that endorse the information about the problem under consideration, according to productions of the type:
\[-f(x_1, x_2, x_3) \equiv -f(x_1, x_2, x_3)\]
\[f_2(\{6, 6\}, \{5, 5, 7\}, \{0, 2\}) = 1 \text{ DoC}\]
\[0, 12 \leq [2, 5, 10] \{0, 2\} \]
\[\text{attribute's domains for } x_{1,2,3} \]

\[J = 1\]

The Degree of Confidence (DoC) is evaluated using the theorem of Pitagoras, i.e., \(\text{DoC} = \sqrt{1 - \Delta^2}\), as illustrated in Figure 1. Here \(\Delta\) stands for the length of the arguments intervals, once normalized.

Below, one has the expected representation of the extensions of the predicates that make the universe of discourse, where all the predicates' arguments are real numbers. They speak for one's confidence that the real values of the arguments fit into the attributes' values ranges referred to above. Therefore, one may have:

\[f_2(\{0, 0.5, 0.5\}, \{0.4, 0.6\}, \{0, 1\}) = 1 \text{ DoC}\]
\[0, 1 \leq [0, 1, 0] \{0, 1\} \]
\[\text{attribute's domains for } x_{1,2,3} \text{ once normalized}\]

\[J = 1\]

The Degree of Confidence (DoC) is evaluated using the theorem of Pitagoras, i.e., \(\text{DoC} = \sqrt{1 - \Delta^2}\), as illustrated in Figure 1. Here \(\Delta\) stands for the length of the arguments intervals, once normalized.

Below, one has the expected representation of the extensions of the predicates that make the universe of discourse, where all the predicates' arguments are real numbers. They speak for one's confidence that the real values of the arguments fit into the attributes' values ranges referred to above. Therefore, one may have:

\[f_2(\{0, 0.5, 0.5\}, \{0.4, 0.6\}, \{0, 1\}) = 1 \text{ DoC}\]
\[0, 1 \leq [0, 1, 0] \{0, 1\} \]
\[\text{attribute's domains for } x_{1,2,3} \text{ once normalized}\]

\[J = 1\]

A CASE STUDY

In order to exemplify the applicability of our approach, we will look at an extension of the relational database model, since it provides a basic framework that fits into our expectations (Liu and Sun 2007), and is understood as the genesis of the LP approach to knowledge representation and reasoning (Neves 1984). As a case study, consider the scenario where a relational database is given in terms of the extensions of the relations depicted in Figure 2, which stands for a situation where one has to manage information in order to evaluate the degradation of parchments. Under this scenario some incomplete and/or unknown data is also available. For instance, in case 1, the age of the parchment is unknown, while the last intervention occurred between 5 (five) and 10 (ten) years.

In Light column of the Physical Effects table 0 (zero) and 1 (one) stands for not exposed and exposed, respectively, while in Temperature column 0 (zero) denotes a value in the range of temperatures, i.e., between 2°C and 18°C whereas 1 (one) stands for values outside this interval. The Humidity column is populated with 0 (zero), 1 (one) according to the Relative Humidity (RH) of the storage location. Thus, 0 (zero) denotes \(\text{RH} < 30\%\); 1 (one) stands for a \(\text{RH}\) ranging in interval [30, 50]; and 2 (two) denotes a \(\text{RH}\) \(\geq 50\%\).

With respect to the Mechanical Effects and the Biological Attacks, affirmed on the last two columns of the General Information and the first three columns of the Chemical Effects tables are filled with 0 (zero) and 1 (one) denoting, respectively, absence/presence/yes. The last column of the Chemical Effects table is populated with 0 (zero), 1 (one), 2 (two) or 3 (three) according to the severity of the effects caused by ink degradation. Hence, 0 (zero) stands for no effects; 1 (one) denotes halos; 2 (two) stands for burnthrough and 3 (three) denotes lacings.

\[f_2(\{0, 0.5, 0.5\}, \{0.4, 0.6\}, \{0, 1\}) = 1 \text{ DoC}\]
\[0, 1 \leq [0, 1, 0] \{0, 1\} \]
\[\text{attribute's domains for } x_{1,2,3} \text{ once normalized}\]

\[J = 1\]
### General Information

<table>
<thead>
<tr>
<th>#</th>
<th>Age</th>
<th>Last Intervention</th>
<th>Inadequate Handling</th>
<th>Occurrence of Disasters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>[5, 10]</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>[650, 700]</td>
<td>8</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>40</td>
<td>400, 425</td>
<td>40</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>#</th>
<th>Environmental Pollution</th>
<th>Dust</th>
<th>Dirt</th>
<th>Ink</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>[650, 700]</td>
<td>8</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>40</td>
<td>400, 425</td>
<td>40</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

### Chemical Effects

<table>
<thead>
<tr>
<th>#</th>
<th>Age</th>
<th>Last Intervention</th>
<th>Inadequate Handling</th>
<th>Occurrence of Disasters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>[5, 10]</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>[650, 700]</td>
<td>8</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>40</td>
<td>400, 425</td>
<td>40</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>#</th>
<th>Environmental Pollution</th>
<th>Dust</th>
<th>Dirt</th>
<th>Ink</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>[650, 700]</td>
<td>8</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>40</td>
<td>400, 425</td>
<td>40</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

### Parchment Degradation

<table>
<thead>
<tr>
<th>#</th>
<th>Age</th>
<th>Last Intervention</th>
<th>Handling/Disasters</th>
<th>Biological Attack</th>
<th>Chemical Effects</th>
<th>Mechanical Effects</th>
<th>Physical Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>[5, 10]</td>
<td>0</td>
<td>1</td>
<td>1 [2]</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>[650, 700]</td>
<td>8</td>
<td>1</td>
<td>0</td>
<td>1 [2]</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>40</td>
<td>400, 425</td>
<td>40</td>
<td>1</td>
<td>3</td>
<td>2 [2]</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>#</th>
<th>Bacteria</th>
<th>Fungi</th>
<th>Moths</th>
<th>Cockroaches</th>
<th>Termites</th>
<th>Larvae</th>
<th>Lice</th>
<th>Rodents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>40</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>#</th>
<th>Light</th>
<th>Temperature</th>
<th>Humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>40</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>#</th>
<th>Gaps</th>
<th>West</th>
<th>Folded</th>
<th>Paint Stain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>40</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

### Biological Attacks

<table>
<thead>
<tr>
<th>#</th>
<th>Parchment Degradation</th>
<th>Age</th>
<th>Last Intervention</th>
<th>Handling/Disasters</th>
<th>Biological Attack</th>
<th>Chemical Effects</th>
<th>Mechanical Effects</th>
<th>Physical Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>1</td>
<td>[5, 10]</td>
<td>0</td>
<td>1</td>
<td>1 [2]</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>[650, 700]</td>
<td>8</td>
<td>0</td>
<td>1</td>
<td>1 [2]</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>40</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>2 [2]</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

### Mechanical Effects

<table>
<thead>
<tr>
<th>#</th>
<th>Gaps</th>
<th>West</th>
<th>Folded</th>
<th>Paint Stain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>40</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

### Physical Effects

<table>
<thead>
<tr>
<th>#</th>
<th>Light</th>
<th>Temperature</th>
<th>Humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>40</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

---

The values presented in the Handling/Disasters, Biological Attack, Chemical, Mechanical and Physical Effects columns of Parchment Degradation table are the sum of the correspondent columns or tables, ranging between [0, 2] [0, 8], [0, 6], [0, 4] and [0, 4], respectively.

Now, we may consider the relations given in Figure 2, in terms of a parch_degrad predicate, depicted in the form:

\[
parch\_degrad: \text{Age}, \text{Last}\_\text{Intervention}, \text{Handling/Disasters}, \text{Biological}\_\text{Attack}, \text{Chemical}\_\text{Effects}, \text{Mechanical}\_\text{Effects}.
\]

\[
\text{Mechanical}\_\text{Effects}, \text{Physical}\_\text{Effects} \rightarrow (0, 1)
\]

where \( \text{parch}\_\text{degrad} \) stands for the predicate \( \text{parch}\_\text{degrad} \), in the form:

\[
\neg \text{parch}\_\text{degrad}(\text{Age}, \text{LI}, \text{H/D}, \text{BA}, \text{CE}, \text{ME}, \text{PE}) \rightarrow \neg \text{parch}\_\text{degrad}(\text{Age}, \text{LI}, \text{H/D}, \text{BA}, \text{CE}, \text{ME}, \text{PE})
\]

\[
\text{parch}\_\text{degrad}(\text{Age}, [5, 10], 0, 1, [1, 2], 3) = 1 \equiv \text{DoC}
\]

\[
\neg \text{parch}\_\text{degrad}(\text{Age}, \text{LI}, \text{H/D}, \text{BA}, \text{CE}, \text{ME}, \text{PE}) \rightarrow \neg \text{parch}\_\text{degrad}(\text{Age}, \text{LI}, \text{H/D}, \text{BA}, \text{CE}, \text{ME}, \text{PE})
\]

\[
\text{parch}\_\text{degrad}(\text{Age}, [5, 10], 0, 1, [1, 2], 3) = 1 \equiv \text{DoC}
\]

\[
\neg \text{parch}\_\text{degrad}(\text{Age}, \text{LI}, \text{H/D}, \text{BA}, \text{CE}, \text{ME}, \text{PE}) \rightarrow \neg \text{parch}\_\text{degrad}(\text{Age}, \text{LI}, \text{H/D}, \text{BA}, \text{CE}, \text{ME}, \text{PE})
\]

\[
\text{parch}\_\text{degrad}(\text{Age}, [5, 10], 0, 1, [1, 2], 3) = 1 \equiv \text{DoC}
\]
In this program, the former clause denotes the closure of predicate parch_degrad, and the next, taken from the extension of the parchement degradation relation shown in Figure 2, presents the information regarding case 1.

\[
\text{parch_degrad(Age, LI, H/D, BA, CE, ME, PE)} \quad \text{not parch_degrad(Age, LI, H/D, BA, CE, ME, PE)}
\]

\[
\text{parch_degrad(0, 0.999, 1, 1, 0.986, 1, 1)} \quad : 1 : 0.855
\]

\[
\text{parch_degrad(0, 0.999, 1, 1, 1)} \quad : 1 : 0.855
\]

where its terms make the training and test sets of the Artificial Neural Network given in Figure 3.

**ARTIFICIAL NEURAL NETWORKS**

Several studies have shown how Artificial Neural Networks (ANNs) could be successfully used to structure data and capture complex relationships between inputs and outputs (Caldeira et al. 2011; Salvador et al. 2013; Vicente et al. 2012). ANNs simulate the structure of the human brain, being populated by multiple layers of neurons, with a valuable set of activation functions. As an example, let us consider the former case presented in Figure 2, where one may have a situation in which the evaluation of the parchements’ degradation is needed. In Figure 3 it is shown how the normalized values of the interval boundaries and their DoC and Qul values work as inputs to the ANN. The output translates the parchments’ degradation and the confidence that one has on such a happening. In addition, it also contributes to build a database of study cases that may be used to train and test the ANN.

The dataset holds information about the factors considered critical in the prediction of degradation state of parchments. Twenty three variables were selected allowing one to have a multivariable dataset with 40 records (Figure 2). These variables were grouped into five main categories, i.e., General Information, Biological Attacks, and Chemical, Physical and Mechanical Effects. Thus, the number of variables used as input of the ANN model was reduced to seven, i.e., the predicate’s arguments were used according to a process of sensitivity analysis, based on their DoC values. A technique used to determine how different values of an independent variable will impact a particular dependent variable under a given set of assumptions.

The dataset used in the training phase it was divided in exclusive subsets through the 4-folds cross validation. In the implementation of the respective dividing procedures, ten executions were performed for each one (one). Moving on, the next step is to transform all the argument values into continuous intervals, and then move to normalize the predicate’s arguments. One may have:

\[
\text{parch_degrad(Age, LI, H/D, BA, CE, ME, PE)} \quad \text{not parch_degrad(Age, LI, H/D, BA, CE, ME, PE)}
\]

\[
\text{parch_degrad(0, 0.999, 1, 1, 0.986, 1, 1)} \quad : 1 : 0.855
\]

\[
\text{parch_degrad(0, 0.999, 1, 1, 1)} \quad : 1 : 0.855
\]

where its terms make the training and test sets of the Artificial Neural Network given in Figure 3.

**ARTIFICIAL NEURAL NETWORKS**

Several studies have shown how Artificial Neural Networks (ANNs) could be successfully used to structure data and capture complex relationships between inputs and outputs (Caldeira et al. 2011; Salvador et al. 2013; Vicente et al. 2012). ANNs simulate the structure of the human brain, being populated by multiple layers of neurons, with a valuable set of activation functions. As an example, let us consider the former case presented in Figure 2, where one may have a situation in which the evaluation of the parchements’ degradation is needed. In Figure 3 it is shown how the normalized values of the interval boundaries and their DoC and Qul values work as inputs to the ANN. The output translates the parchments’ degradation and the confidence that one has on such a happening. In addition, it also contributes to build a database of study cases that may be used to train and test the ANN.

The dataset holds information about the factors considered critical in the prediction of degradation state of parchments. Twenty three variables were selected allowing one to have a multivariable dataset with 40 records (Figure 2). These variables were grouped into five main categories, i.e., General Information, Biological Attacks, and Chemical, Physical and Mechanical Effects. Thus, the number of variables used as input of the ANN model was reduced to seven, i.e., the predicate’s arguments were used according to a process of sensitivity analysis, based on their DoC values. A technique used to determine how different values of an independent variable will impact a particular dependent variable under a given set of assumptions.

The dataset used in the training phase it was divided in exclusive subsets through the 4-folds cross validation. In the implementation of the respective dividing procedures, ten executions were performed for each one (one). Moving on, the next step is to transform all the argument values into continuous intervals, and then move to normalize the predicate’s arguments. One may have:

\[
\text{parch_degrad(Age, LI, H/D, BA, CE, ME, PE)} \quad \text{not parch_degrad(Age, LI, H/D, BA, CE, ME, PE)}
\]

\[
\text{parch_degrad(0, 0.999, 1, 1, 0.986, 1, 1)} \quad : 1 : 0.855
\]

\[
\text{parch_degrad(0, 0.999, 1, 1, 1)} \quad : 1 : 0.855
\]
CONCLUSIONS AND FUTURE WORK

To set a timeline to the maintenance of parchments is a hard and complex task, which needs to consider many different conditions. On the other hand, once the parameters to assess DoP are not fully represented by objective data (i.e., are of types unknown or not permitted, taken from a set or even from an interval), the problem was put into the area of problems that must be tackled by Artificial Intelligence based methodologies and techniques for problem solving. In fact, the computational framework presented above uses powerful knowledge representation and reasoning methods to set the structure of the information and the associate inference mechanisms. One’s approach may revolutionize prediction tools in all its variants, making it more complete than the existing ones. It enables the use of normalized values of the interval boundaries and their respective DoP and DoC values, as input to the ANN. The output translates the DoP and the confidence that one has on such a happening. Indeed, the main contribution of this work is to be understood in terms of the evaluation of the DoP, and the possibility to address the issue of incomplete information.

Future work may recommend that the same problem must be approached using others computational frameworks like Case Based Reasoning, Genetic Programming or Particle Swarm, just to name a few.

ACKNOWLEDGMENTS

This work has been supported by FCT – Fundação para a Ciência e Tecnologia within the Project Scope UID/ECC/00019/2013.

REFERENCES


